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Comparison of tribological performance of zinc dialkyldithiophosphate (ZDDP) in poly-alpha-olefin (PAO) and palm oil-based trimethylopropane (TMP) ester

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ABSTRACT – Due to environmental legislations, automotive industry is striving hard to shift from mineral/synthetic oils to environmental friendly ones such as vegetable oils. In this study, effectiveness of ZDDP in enhancing the tribological properties of steel/steel contact, when used in combination with palm-oil based TMP ester, has been investigated and the results are compared with that of PAO. Friction and wear experiments were carried out using four-ball tribo-testing machine. TMP and TMP+PAO offered low values of friction compared to PAO. In addition, ZDDP-derived tribofilm was detected on the interacting surfaces, when TMP+PAO+ZDDP lubricant was used, resulting in decreased wear.

1. INTRODUCTION

Nowadays, automotive sector are under immense pressure of ecological authorities demanding vehicles compatible with environmental friendly and biodegradable lubricants [1]. In order to meet this challenge, automotive manufacturers are working closely with their lubricant partners. The most commonly used base oils in commercial lubricants are either derived from petroleum or synthetic [2]. Because of their hazardous effects on the environment and difficult waste management, there is an ongoing trend to shift to biodegradable base oils [3]. Chemically modified vegetable oils such as palm-oil based trimethylopropane (TMP) esters are one of the potential candidates for alternate lubricant base oils due to their extraordinary lubricating properties [4]. Some of the favorable properties of vegetable oils as lubricants include high flash point, enhanced biodegradability, non-toxicity and enhanced viscosity index [5]. Since, most of the commonly used lubricant additives are optimized for conventional base oils; therefore, there is a need to evaluate the effectiveness of these additives in bio base oils. In this paper, most commonly used antiwear additive zinc dialkyldithiophosphate (ZDDP) is used in combination with synthetic, bio and blended base oils to compare their tribological performance using four-ball machine. Scanning Electron Microscope (SEM) is used to measure the wear scar diameters (WSD) of balls which represent wear behavior of a particular lubricant/material pair. Energy dispersive x-ray (EDX) spectroscopy is deployed to detect the elements deposited on the interacting surfaces as a result of tribochemical interaction with the lubricants using tabletop Phenom ProX (Phenom-World, Netherlands).

2. METHODOLOGY

Tribological experiments were conducted on four-ball machine using AISI 52100 steel balls according to ASTM D 4172-B standard. The material properties of the balls and tribo-test conditions are summarized in Table 1 and Table 2 respectively. Before and after each test, balls and machine components were washed with toluene to remove contaminants and residual lubricant films. Three balls at the bottom were held stationary in a lubricant containing pot and pressed against a rotating top ball establishing a point contact.

Table 1 Material properties of AISI 52100 steel balls.

Properties	Specifications
Diameter	12.7 mm
Hardness	64-66 HRC
Surface roughness	0.03 – 0.04 Ra
Density	7.80 g/cm^3

Table 2 Four-ball tribo-test conditions.

Physical Quantity	Specifications
Load	40 kg (392.4 N)
Speed of top ball	1200 RPM
Duration	3600 sec
Temperature	75°C

Table 3 Composition of additivated and non-additivated lubricants.

Lubricant	PAO	TMP	ZDDP
PAO	100	-	-
TMP	-	100	-
TMP+PAO	50	50	-
PAO+ZDDP	99	-	1
TMP+ZDDP	-	99	1
TMP+PAO+ZDDP	49.5	49.5	1

PAO, TMP, and a blend of TMP & PAO mixed in a ratio of 1:1 by weight were used as base oils. In addition to this, three additivated lubricants were also prepared by mixing commonly used antiwear additive ZDDP at a concentration of 1.0 wt%. Composition details of the lubricants used in this study are given in Table 3. For each tribo-test, 10 ml of lubricant was used.

3. RESULTS AND DISCUSSION

Tribological performance of base oils and formulated lubricants was evaluated by comparing their coefficients of friction and wear scar diameters. In Figure 1, it can be seen that lowest value of friction was observed with TMP whereas PAO+ZDDP offered maximum friction between the interacting surfaces. Generally, an increase in friction was observed when ZDDP was mixed with base oils. Contrary to that, appreciable improvement in wear resistance of steel/steel contact was witnessed with lubricants containing ZDDP especially with TMP+PAO (Figure 2). Similar behavior was also observed in case of PAO but unfavorable effect of ZDDP was experienced on the wear performance when used in TMP. SEM micrographs showing WSDs of stationary steel balls with additivated and non-additivated lubricants are shown in Figure 3. In Figure 3, it can be seen that adhesive wear was the dominant cause of high wear rates in base oils. Inclusion of ZDDP not only changed the wear mechanism to polishing wear but also prevented the asperity breakages by forming tribofilms especially in case of TMP+PAO.

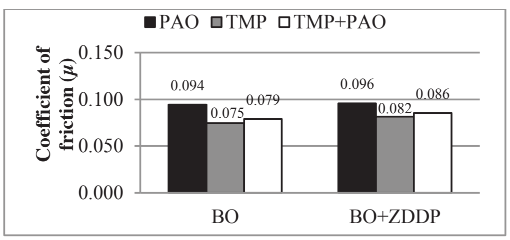

Figure 1 Coefficient of friction for steel/steel contact with additivated and non-additivated lubricants.

According to EDX results, increase in zinc and phosphorus content was observed on the steel balls with PAO+ZDDP and TMP+PAO+ZDDP. This demonstrates that additive-derived tribofilm consisting of ZnS, ZnO and $ZnSO_4$ was formed on the interacting surfaces resulting in wear reduction. Negligible change in the concentration of above mentioned elements was seen in case of TMP+ZDDP. This shows that no tribochemical interaction took place resulting in highest wear rates with TMP+ZDDP among the tested lubricants.

4. CONCLUSIONS

In this study, effectiveness of ZDDP in different base oils is evaluated. In additivated and non-additivated form, bio-based lubricants demonstrated better tribological performance as compared to their synthetic counterparts. Tribochemical interaction between interacting surfaces and ZDDP was observed when PAO and TMP+PAO were used as base oils whereas no such behavior was observed with TMP+ZDDP. From these observations, it can be concluded that TMP in combination with PAO has a potential to be used as base oil in automotive lubricants.

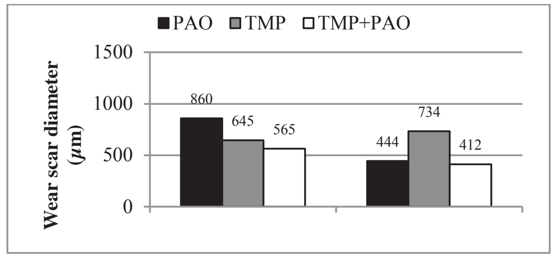

Figure 2 Wear scar diameters for steel/steel contact with additivated and non-additivated lubricants.

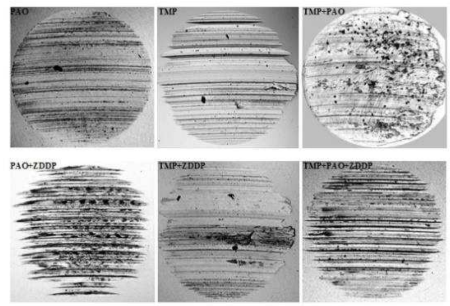

Figure 3 SEM micrographs of wear scar diameters with additivated and non-additivated lubricants.

5. ACKNOWLEDGEMENT

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